MEASUREMENTS OF PM_{10} EMISSION FACTORS FROM UNPAVED ROADS IN ARIZONA TO DETERMINE THE EFFICIENCY OF DUST SUPPRESANTS

DRAFT FINAL REPORT

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1.0 PROJECT DESCRIPTION AND OBJECTIVES

1.1 Background

The expression contained into the EPA document AP-42 for predicting emission rates and has been widely used all over the country to estimate the fraction of PM_{10} originating from paved roads:

$$E = k(sL/2)^{0.65} (W/3)^{1.5} \text{ g/VKT} \qquad (1)$$

where:

E = PM emission factor in the units shown
k = A constant dependent on the aerodynamic size range of PM (1.8 for $PM_{2.5}$; 4.6 for PM_{10})
sL = Road surface silt loading of material smaller than 75µm in g/m^2
W = mean vehicle weight in tons
VKT = vehicle kilometer traveled

Equation (1) was derived by measuring the total flux across roadways using a PM_{10} monitoring array and based solely on surface silt loading.

We developed an alternative technique using a vehicle equipped real-time PM sensors to measure concentrations in front of the vehicle and in its rear wake (Fitz and Bufalino, 2002; Fitz et al. 2005a,b). In this approach the PM_{10} concentrations are measured directly on moving vehicles in order to improve the measurement sensitivity for estimating the emission factors for vehicle on paved roads. Optical sensors are used to measure PM_{10} concentrations with a time resolution of approximately two seconds. Sensors were mounted in the front and behind the vehicle in the well-mixed wake. A special inlet probe was designed to allow isokinetic sampling under all speed conditions. The emission factors are based on the concentration difference between front and back of the test vehicle and the frontal area. The test system has been designated as SCAMPER (System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways)

This SCAMPER technique is useful for quickly surveying large areas and for investigating hot spots on roadways caused by greater than normal deposition of PM_{10} forming debris. While there is an AP-42 equation for unpaved roads that has silt content as an independent variable, the SCAMPER approach directly measures emissions and does not depend on independent variables. The approach is therefore as valid for unpaved roads as for paved roads.

1.2 Objective

The primary objective of this project was to determine the effectiveness in dust suppressants on unpaved state highways in Arizona.

1.3 Approach

We used the CE-CERT developed SCAMPER (System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways) to determine vehicle PM emission factors by measuring the PM concentrations in front of and behind the vehicle using real-time sensors. This system was used to measuring PM_{10} emission rates on state routes 88 and 288 on sections that were treated with a dust suppressant and on contiguous untreated sections. The efficiency of the dust suppressant was then calculated from the difference between the mean emission rates for each type of road segment.

This SCAMPER has five major components:

1) Sampling Inlet

> An inlet for the real-time PM sensors was used that allowed sampling as isokinetically as possible over the full range of vehicle speeds. This involves a bypass flow system that is adjusted to vehicle speed with a PC using GPS speed data.

2) PM_{10} Sensors

> DustTrak optical PM sensors with PM_{10} inlets are used.

3) Sampling Trailer

> From our studies to determine concentrations in the vehicle wake the sampling position behind the vehicle was optimized. This position required using a trailer to mount the sampling inlet. The trailer was designed to disturb the vehicle wake as little as possible. In addition, the trailer holds the bypass flow system.

4) Position Determination

> A Garmin GPS Map76 global positioning system was used to determine vehicle location and speed.

5) Data Collection

> A PC was used to collect data from GPS and PM_{10} measuring devices. Data was stored as two-second averages. The PC also was used to automatically adjust the sample inlet bypass flow to maintain isokinetic particle sampling using a 10-second running average of vehicle speed based on the GPS.

Figure 1.1 shows front and rear photographs of the SCAMPER. The tow vehicle is a 1995 Chevrolet Suburban with a custom trailer with an extended hitch.

Figure 1-1. Photographs of the front and rear of the SCAMPER.

2.0 FIELD MEASUREMENTS

Field measurements of PM_{10} emission rates were made on two different state highways, routes, SR88 and SR288. Figure 2-1 is a map showing the location of these routes that were used with respect to Phoenix, AZ. In this map the emission rates are represented as circles with the shading becoming darker as the emission rates become larger. The emission rates will be discussed in more detail in section 4. Figures 2-2 and 2-3 show more detailed maps of the portions used on states routes 88 and 1888, respectively. Figure 2-4 shows the SCAMPER being used on SR88. The SCAMPER test vehicle was operated at speeds consistent with safe operation and that observed of other vehicles.

The segment of state route 88 between mile point 220.1 and mile point 227.5 was treated with Envirotac II Acrylic copolymer at a rate of 1 gallon per 36 square feet. To the west the road was paved and to the east it was unpaved gravel. The section between miles 226.5 and 227.5 was first treated in late 2003 and the section between miles 220.1 and 226.5 was treated in May 2005. The SCAMPER testing was conducted from Tortilla Flats (GPS coordinates 33.5268 by –111.3896) eastbound on paved road to mile 220.1 (GPS coordinates 33.5483 by –111.2563) where the road transitioned from paved to treated gravel. The treated section ended at mile 227.5 and the SCAMPER vehicle continued eastward on untreated gravel until reaching GPS coordinates 33.5829 by –111.22143 where it turned around and headed westbound back to Tortilla Flats. Four circuits were completed on October 10, 2005. On one circuit filters were installed on the DustTrak inlets to confirm that there was no significant signal due to the extreme bouncing that occurred on these unpaved rough roads.

In 2004 the segment of SR 188 between mile points 274.7 and 280.5 was treated by milling 6in of the base material that was treated with a 1:1 ratio of SS1 followed by an application of CRS II Emulsified liquid at a rate of 0.5 gallon per square yard and then 28 pounds per square yard of 3/8 in chips. The road was untreated gravel on both sides of the treated section. The SCAMPER test route consisted of a circuit starting on the south approximately 1/4mile from the treated section (GPS coordinates of 33.7468 by –110.9624), covering the treated section (GPS coordinates 33.7496 by –110.9650 at the southern end and 33.7879 by –110.9714 at the northern end) and continue north on the gravel for another quarter mile (GPS coordinates of 33.7935 by –110.9719.

Figure 2-1. Map of the test segments used on SR88 and SR188.

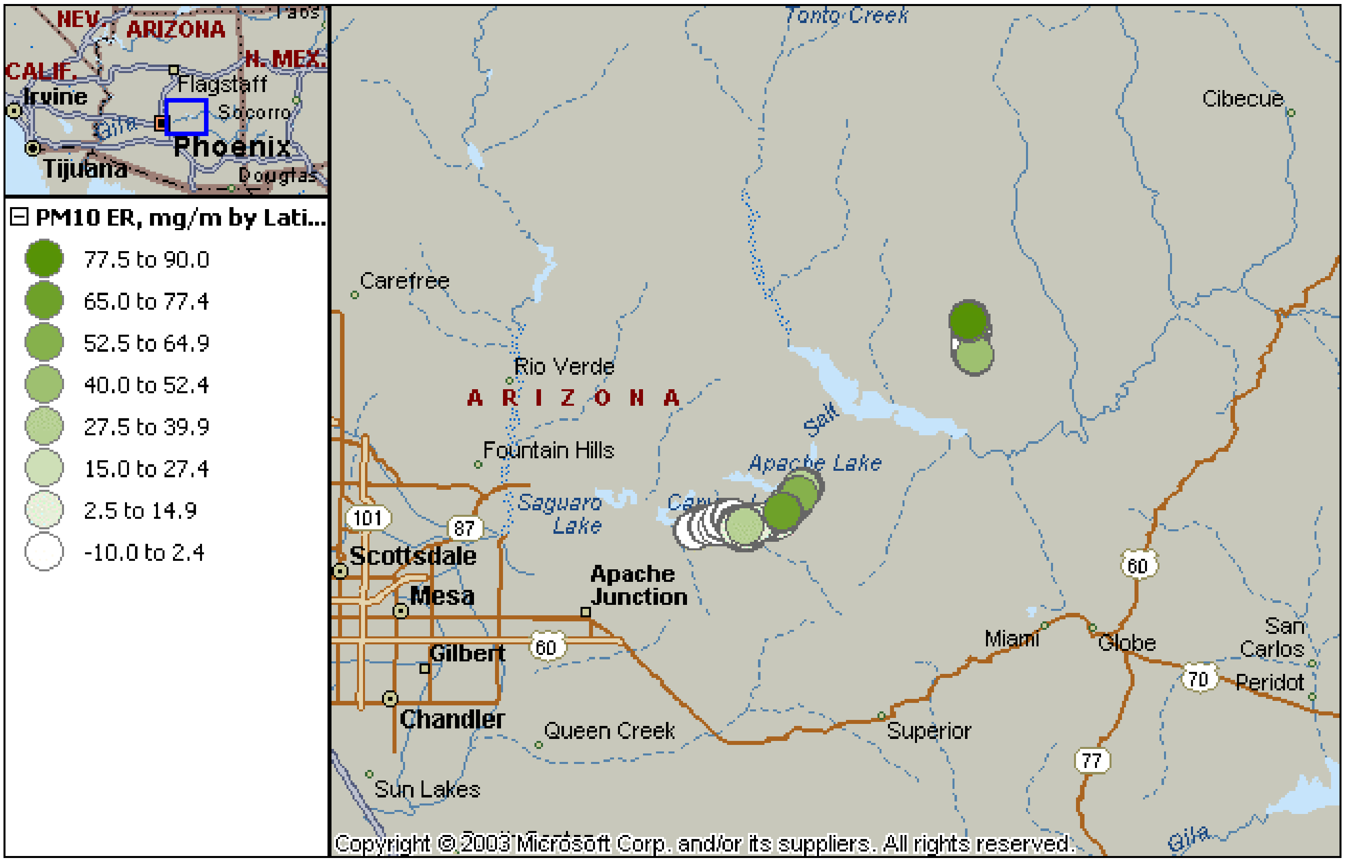

Figure 2-2. Map of the test segments used on SR88

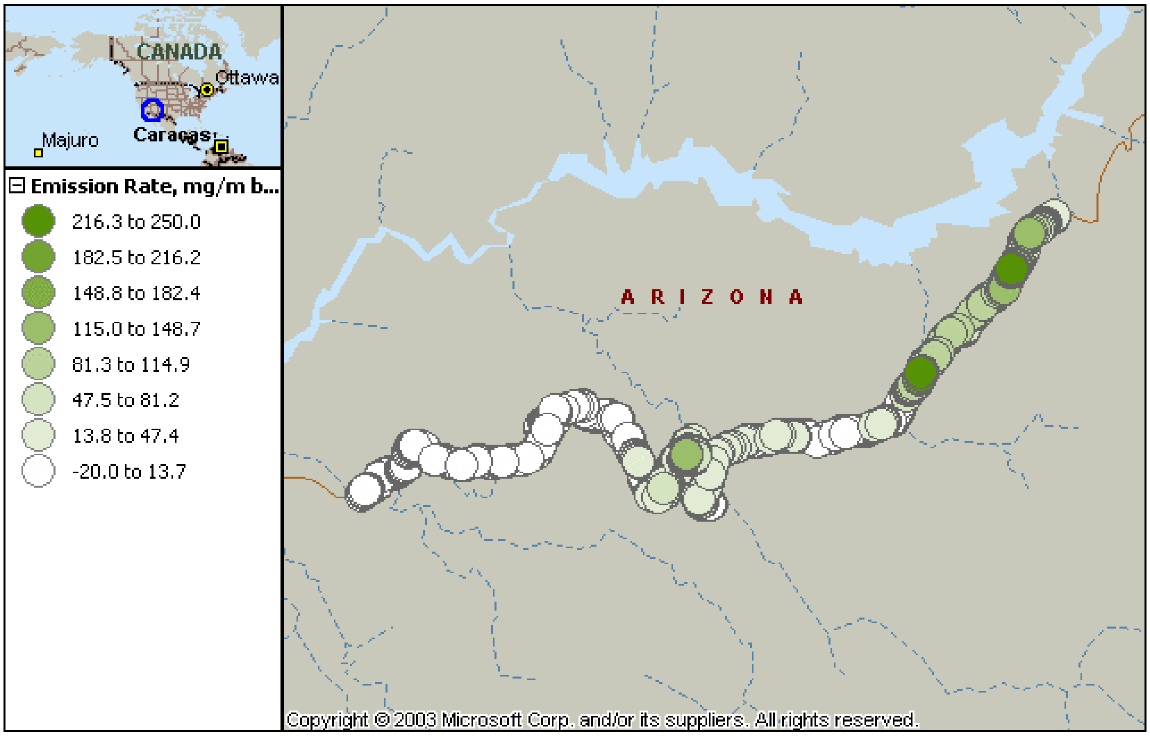

Figure 2- 3. Map of the test segments used on SR188

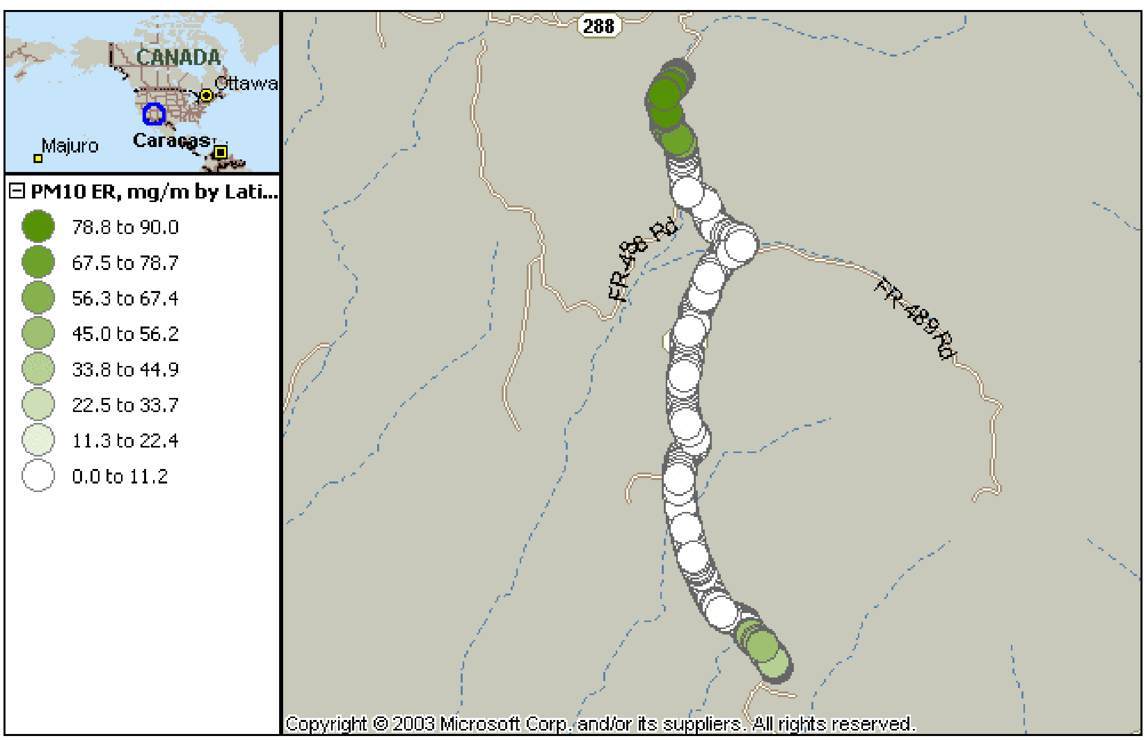

Figure 2-4. Photograph of the SCAMPER testing SR88.

3.0 DATA QUALITY

- Data Capture

The data capture form the DustTrak analyzers was 100% for the testing of SR88 but the rear analyzer stopped working during four segments of the last two circuits of SR188. The problem appears to be due to the harsh ride caused the rough road. Typically the instrument would simply stop working after hitting a particularly severe bump, most likely due to a brief interruption of power. There were also instances of spikes due to hitting bumps where the analyzer kept working. As described in the next section, these were removed during data processing. Additional vibration isolation appears to be needed for testing rough, unpaved roads.

- DustTrak Drift

The zero of the DustTrak was determined before, after, and at least once during the test runs. The drift during the course of the each test day was less than a few thousandths of a mg/m^3, near the 0.001 mg/m^3 detection limit of the instrument. The data for each test run was corrected for zero offset using the mean zero response for that day.

4.0 DATA SUMMARY

4.1 DATA VALIDATION

The data acquisition system recorded all data digitally with 100% capture. As mentioned above, we found that the output of the rear DustTrak occasionally spiked, either positive or negative, most likely due to physical shock. These spikes always showed up on two consecutive seconds. These were unlikely to be associated with an actual PM_{10} concentration as concentrations rarely change to that degree in less than one second. This two-second characteristic of this noise spike is also expected from the internal averaging and output characteristics of the DustTrak. On the time constant we selected (which is the shortest available) the DustTrak output is a two-second running average that is updated every second.

A large spike in a one-second period will therefore show up as two smaller spike for two consecutive seconds. To filter this noise we tabulated the data as 5-second running medians. Two-second spikes therefore would be removed from the data set. At the same time we calculated the running medians we also corrected for the zero response for each analyzer.

4.2 DATA SUMMARY

The net PM_{10} concentration is determined by subtracting the concentration from the front DustTrak from that of the rear. Since the DustTrak data is noisy at the shortest time constant, we plotted the data as a 10-second running average of the 5-second running medians. We have found that this period of a running average produces higher quality data although the time resolution is not as great. This is an inherent limitation of the DustTrak instrument. We then multiplied the net PM_{10} concentration by $3.66m^2$, the frontal area of the test vehicle, to obtain the PM_{10} emission rate in units of mg/m.

The following subsections describe each day of data collected. This is accomplished with a time series plot and a location plot. The time series plots give good overviews of the data, especially for comparison with other test days. Since the speed varies from day to day, the location data, however, is approximate. The location plots are useful to pinpoint hot spots, but it is difficult to compare data with other days. The combination of the two presentations therefore gives a comprehensive view of the data. The data are also summarized as segment means.

4.2.1 SR88 OCTOBER 10, 2005

Figure 2-2 summarizes the data on a map. Progressing from left to right the emissions increase as the SCAMPER transverses paved, treated unpaved, and untreated unpaved. Figure 4-1 shows the time series of PM_{10} emission rates calculated as a running ten-second average for periods when the running average speed was greater than 10 mph. The units are in mg/m. The data from treated and untreated unpaved roads are highlighted, as are the paved road sections. Table 4-1 summarizes the data. The average emission rate of the treated gravel section was approximately five times lower than the untreated gravel section. In both cases the average speed was near 20 mph. Spikes in the emission rate are observed at repeatable times for both treated and untreated sections, likely indicating road surfaces containing higher fractions of finer soil. Based on the reproducibility of the segment emission rate data, the precision of the measurements for both the treated and untreated sections was high, especially considering the potential operational variability from run to run. While standard deviations should not be calculated from three test runs, the precision of the measurement is about 20%, which is consistent with our much larger database from paved road measurements.

Figure 4-1 Time series plot of PM_{10} emissions during the test conducted on SR88 October 10, 2005.

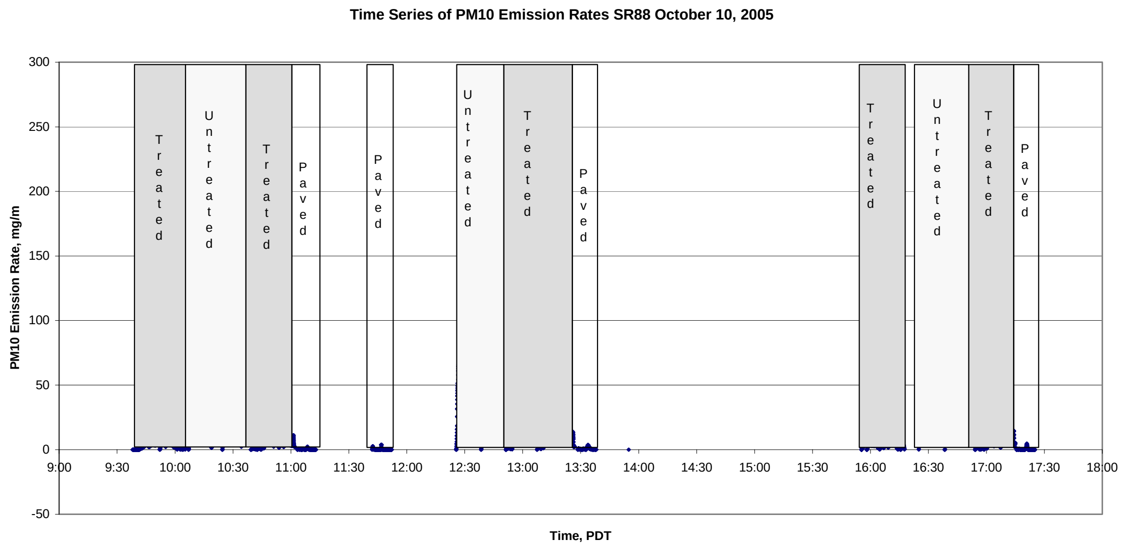

Table 4-1. Summary of mean PM_{10} emission rates for the test route on SR88 on October 10, 2005

Means	Circuit1	Circuit2	Circuit3	Circuit4	Overall Means
Treated Time Eastbound	09:41-10:06			15:55-16:18	
Treated Mean ER Eastbound	**8.9**	**ND**	**ND***	**8.1**	**8.5**
Treated Mean Speed Eastbound	19.8	NA	NA	20.1	20.0
Untreated Time Eastbound	10:07-10:19	12:26-12:36		16:25-16:35	
Untreated Mean ER Eastbound	**51.6**	**60.5**	**ND***	**42.8**	**51.6**
Untreated Mean Speed Eastbound	17.1	18.7	NA	19.6	18.5
Untreated Time Westbound	1034-10:37	12:38-12:50		16:38-16:47	
Untreated Mean ER Westbound	**47.2**	**61.4**	**ND***	**63.0**	**57.2**
Untreated Mean Speed Westbound	17.5	16.6	NA	20.9	18.3
Treated Time Westbound	10:39-11:02	12:51-13:27		16:54-17:15	
Treated Mean ER Westbound	**8.5**	**13.8**	**ND***	**13.3**	**11.9**
Treated Mean Speed Westbound	19.0	18.9	NA	20.8	19.6
Paved Road Westbound Time	11:03-11:13	13:29-13:38		17:16-1725	
Paved ER Westbound to Tortilla Flats	**0.3**	**0.7**	**ND***	**0.3**	**0.4**
Paved Speed Westbound to Tortilla Flats	33.1	32.9	NA	33.5	33.1
Paved Road Eastbound Time	11:42-11:52				
Paved ER Eastbound from Tortilla Flats	**0.3**	**ND***	**ND***		**0.3**
Paved Speed Eastbound from Tortilla Flats	31.8	NA	NA		31.8
Untreated Overall Mean Emission Rate, mg/m					**54.4**
Treated Overall Mean Emission Rate, mg/m					**10.5**
Paved Road Overall Mean Emission Rate, mg/m					**0.4**
ND No Data-Rear DustTrak failed partway into test					
ND* Filtered air control					
NA-Not Applicable					

4.2.2 SR 188 - October 11, 2005

Figure 2-3 summarizes the data on a map. The higher emissions at the top and bottom of the section are from the unpaved segments while the much lower ones are clearly seen in the middle. Figure 4-2 shows the time series of PM_{10} emission rates calculated as a running ten-second average for periods when the running average speed was greater than 10 mph. The units are in mg/m. The data from treated and untreated unpaved roads are highlighted. Table 4-1 summarizes the data. The average emission rate of the treated gravel section was approximately sixty times lower than the untreated gravel section. In addition, the average speed on the untreated sections was nearly half that of the treat section (15.5 vs 32.5 mph). Spikes in the emission rate are observed at repeatable times for only untreated section, likely indicating road surfaces containing higher fractions of finer soil. The PM_{10} emission rate from the treated section was nearly as low as the asphalt paved portion of SR88. Since SR88 had a higher traffic density than SR188, the emissions from its paved segment are expected to be lower than if a segment of SR188 were paved. We therefore conclude that the PM_{10} emissions from the treated portion of SR188 is what would be expected of asphalt pavement. Based on the replicate circuits, the precision of the measurement is also approximately 20%.

Figure 4-2 Time series plot of PM_{10} emissions during the test conducted on October 11, 2005.

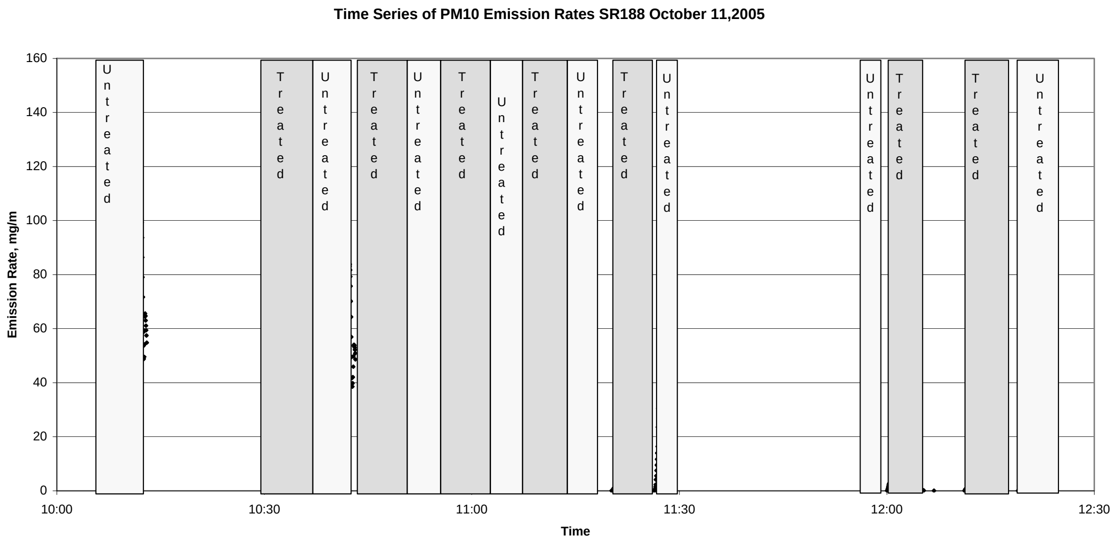

Table 4-2. Summary of mean PM_{10} emission rates for the test route on SR188 on October 11, 2005

Means	Circuit1	Circuit2	Circuit3	Circuit4	Circuit 5	Overall Means
South Untreated Time Northbound	10:05-10:13	10:53-10:56	11:17-11:18	11:45-11:46	12:08-12:10	
South Untreated Mean ER Northbound	**72.9**	**29.4**	**22.7**	**ND***	**ND**	**41.6**
South Untreated Mean Speed Northbound	19.1	13.2	12.5	NA	NA	14.9
Treated Time Northbound	10:31-10:37	10:57-11:03	11:20-11:26	11:40-11:52	12:11-12:17	
Treated Mean ER Northbound	**0.5**	**0.4**	**0.4**	**ND***	**0.5**	**0.4**
Treated Mean Speed Northbound	30.6	32.1	32.9	NA	33.5	31.9
North Untreated Time Northbound	10:38-10:40	11:04-11:06	11:26-11:28	11:52-11:54	12:19-12:20	
North Untreated Mean ER Northbound	**26.8**	**28.7**	**40.2**	**ND***	**39.3**	**31.9**
North Untreated Mean Speed Northbound	13.6	26.6	14.1	NA	15.7	18.1
North Untreated Time Southbound	10:40-10:43	11:07-11:08	11:35-11:36	11:57-11:59	12:23-12:24	
North Untreated Mean ER Southbound	**48.9**	**40.3**	**ND***	**39.8**	**45.4**	**43.0**
North Untreated Mean Speed Southbound	15.2	15.3	NA	15.2	15.7	15.2
Treated Time Southbound	10:45-10:52	11:09-11:15	11:37-11:42	12:00-12:05	12:26-12:31	
Treated Mean ER Southbound	**0.7**	**0.7**	**ND***	**0.9**	**ND**	**0.8**
Treated Mean Speed Southbound	30.9	32.4	NA	34.9	NA	32.7
South Untreated Time Southbound	10:52-10:53	11:15-11:16	11:43-11:44	12:07-12:08	12:32-12:33	
South Untreated ER Southbound	**16.4**	**18.0**	**ND***	**ND**	**ND**	**17.2**
South Untreated Speed Southbound	12.8	12.9	NA	NA	NA	12.8
Untreated Overall Mean Emission Rate, mg/m						**36.1**
Treated Overall Mean Emission Rate, mg/m						**0.6**
ND* = No Data- filtered air control						
ND = Rear DustTrak broke						

5.0 SUMMARY AND CONCLUSIONS

The effectiveness of using dust suppressants to reduce PM_{10} reduction from unpaved roads was quantified for segments of SR88 and 188. The suppressant applied to SR88 five months ago reduced PM_{10} emissions by a factor of five. The suppressant applied to SR188 a year ago reduced PM_{10} emissions by a factor of sixty. The SCAMPER has been shown to collect reliable emission rates from unpaved roads with a precision of approximately 20%. Additional vibration isolation should be added to increase data capture for future measurements on upaved roads.

6.0 REFERENCES

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